Light meson spectroscopy at VEPP-2000 e^+e^- collider - latest results

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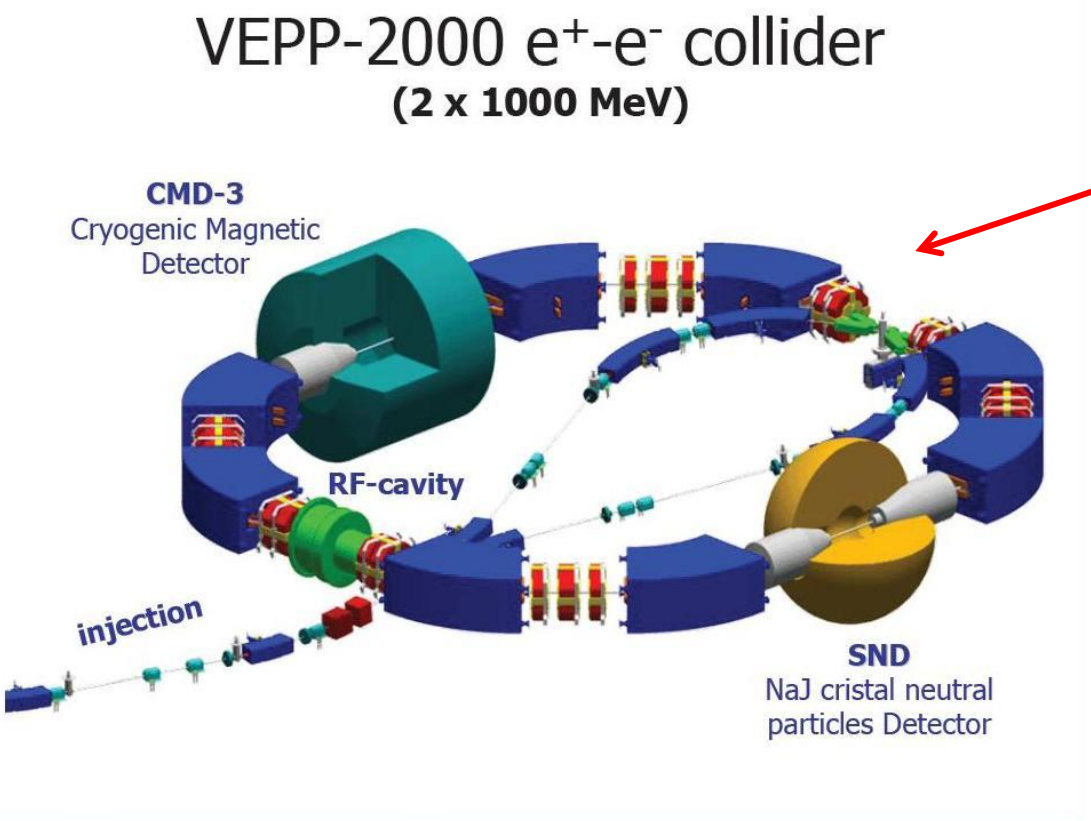
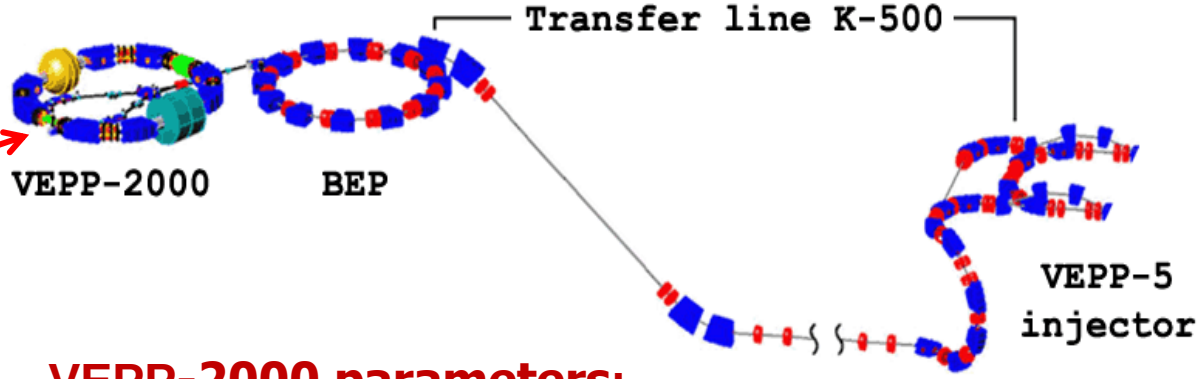
Outline

1. Collider, detectors, experiments
2. Physical results
3. $\rho, \omega, \phi \rightarrow \pi^0\gamma$ decays in $e^+e^- \rightarrow \pi^0\gamma$ process
4. $\phi(1020)$ decays to K^+K^- , K_SK_L, $\pi^+\pi^-\pi^+\pi^-$,
5. Manifestation of $a^0(980)$ in $e^+e^- \rightarrow \rho a^0, \omega a^0$ final states
6. Electron widths of $\eta'(958)$, $\eta(550)$
8. Conclusions

VEPP-2000 collider, in operation since 2010



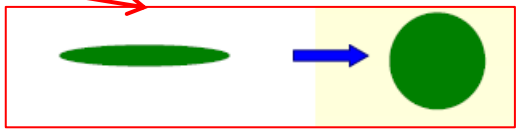


VEPP-2000 parameters:

- c.m. energy E=0.3-2.0 GeV
- round beam optics
- Luminosity at E=1.8 GeV

1×10^{32} cm^{-2} sec^{-1} (project)

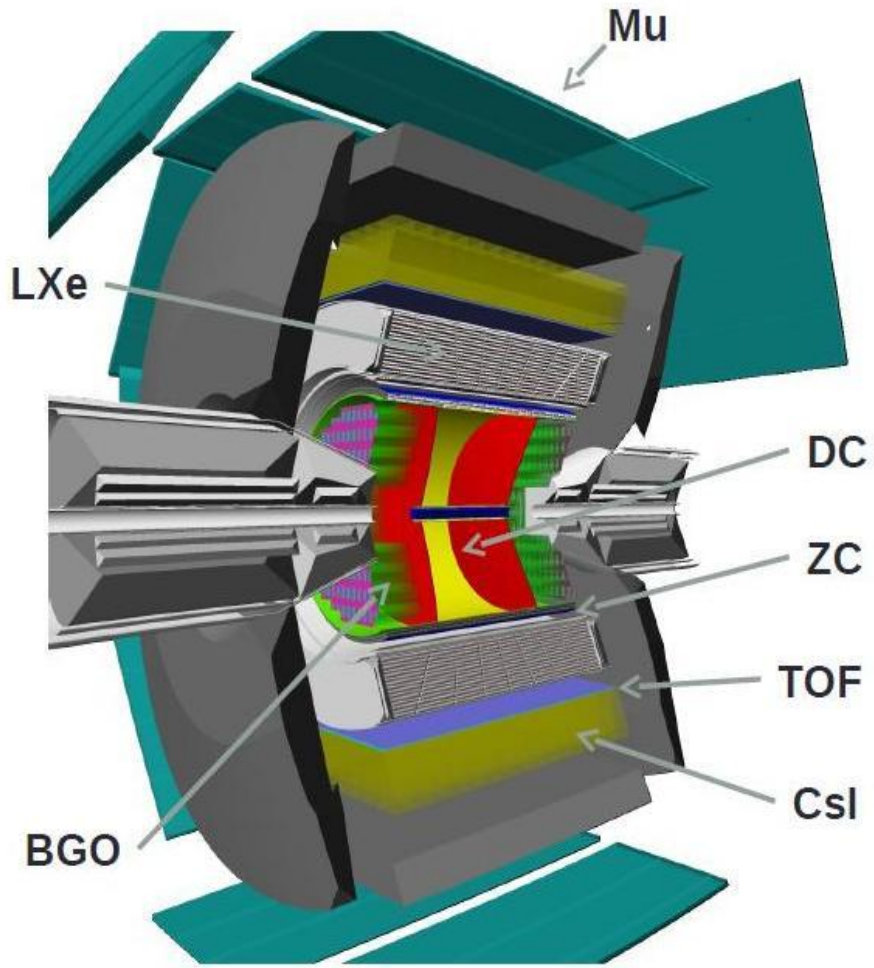
2×10^{31} cm^{-2} sec^{-1} (achieved)

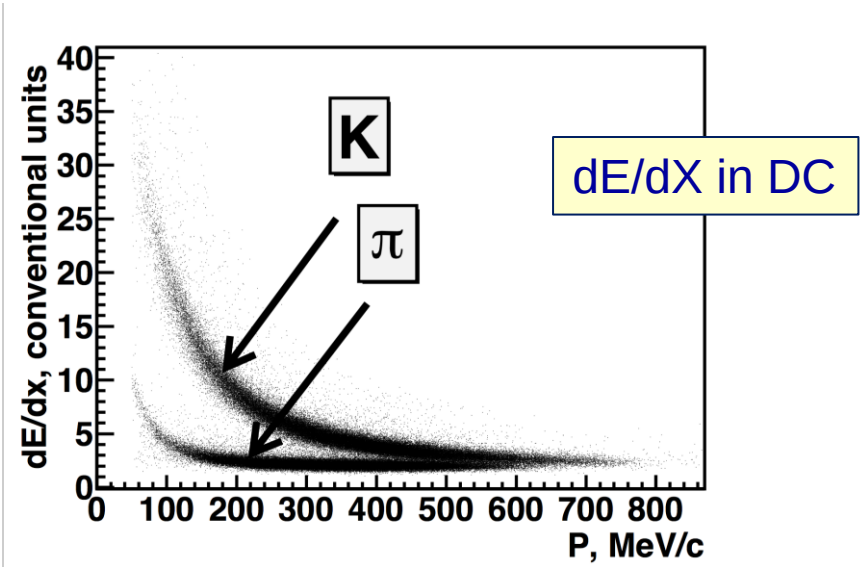


Now (March 12, 2017) :

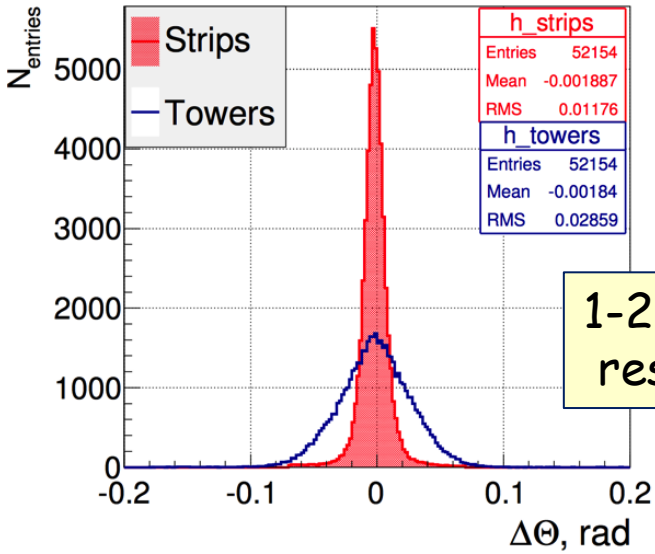
E=1.8 GeV, L ≈ 2-3$\times10^{31}$ cm^{-2} sec^{-1}

CMD-3 detector



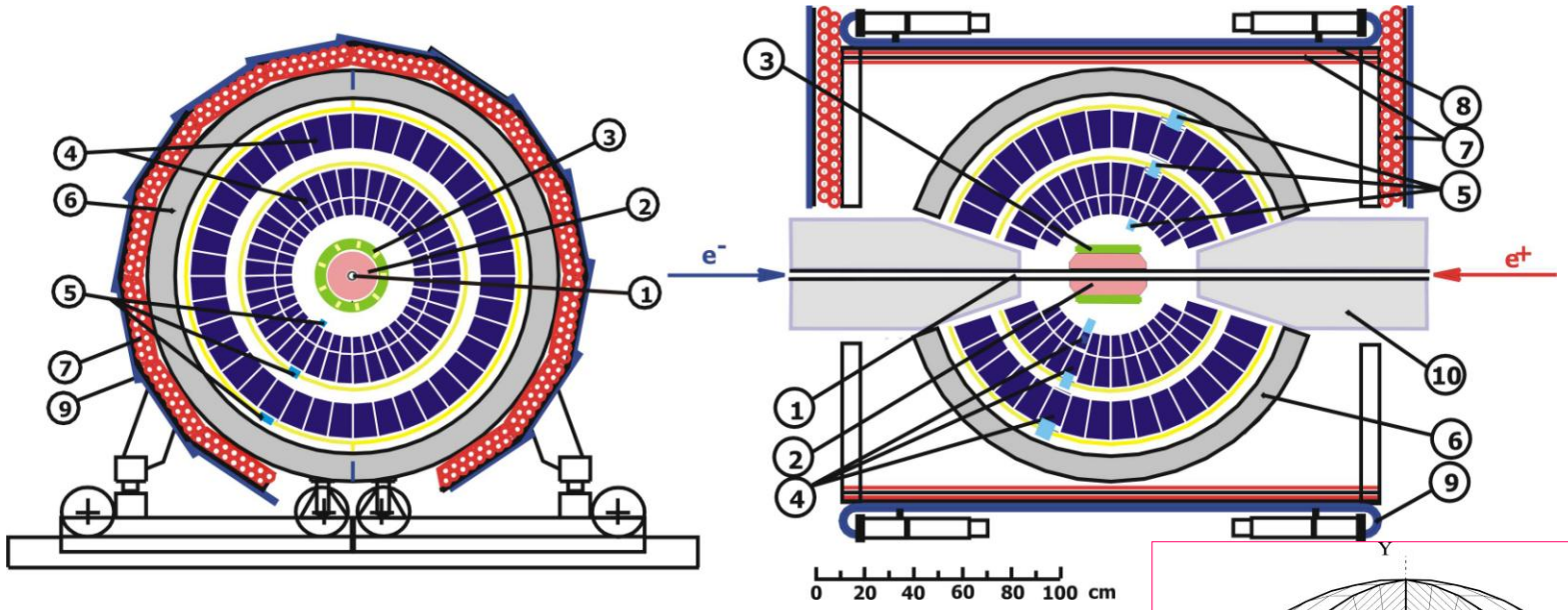


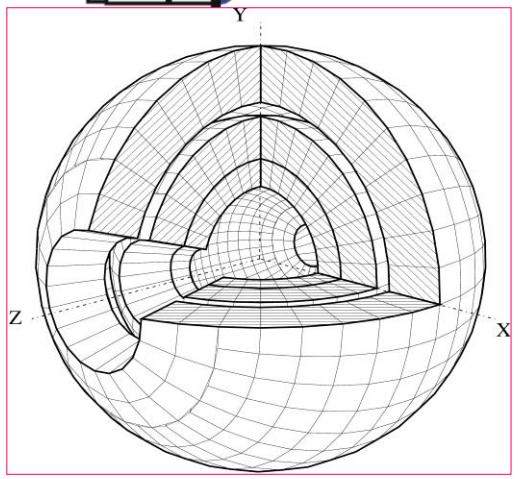
dE/dX in DC



1-2 mm conversion point resolution for photons

SND detector (1994)





1 **– vacuum chamber, 2 – tracking DC,**
3 – aerogel n=1.13, 1.05 4 – NaI(Tl) crystals,
5 – phototriodes, 6 – absorber, 7–9 – muon detector, 10 – SC solenoids

SND parameters:

Main parameters:

Calorimeter:

Energy resolution:

$$\frac{\sigma_E}{E} = \frac{4.2\%}{\sqrt[4]{E(GeV)}}$$

Angular resolution:

$$\sigma_\phi = \frac{0.82^\circ}{\sqrt{E(\mathrm{GeV})}} \oplus 0.63^\circ$$

Tracking system:

Angular resolution:

$$\sigma_M = 0.55\theta,\ \sigma_\theta = 1.2^\circ$$

Spatial resolution:

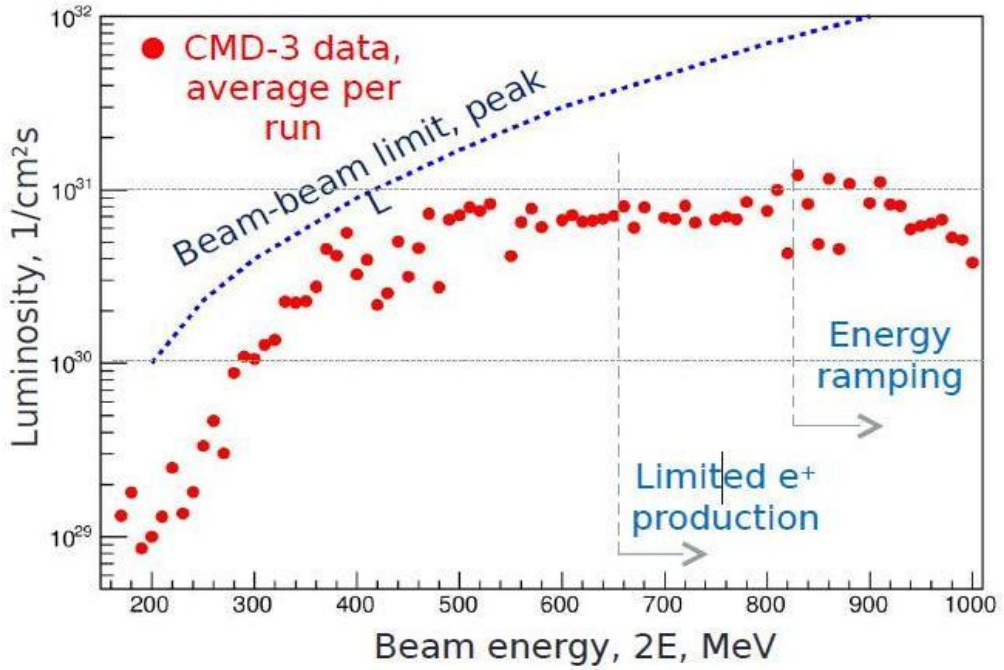
$$\sigma_R = 0.12cm, \sigma_Z = 0.45cm$$

Aerogel counters:

π/K separation E<1 GeV

Experiments at VEPP-2000

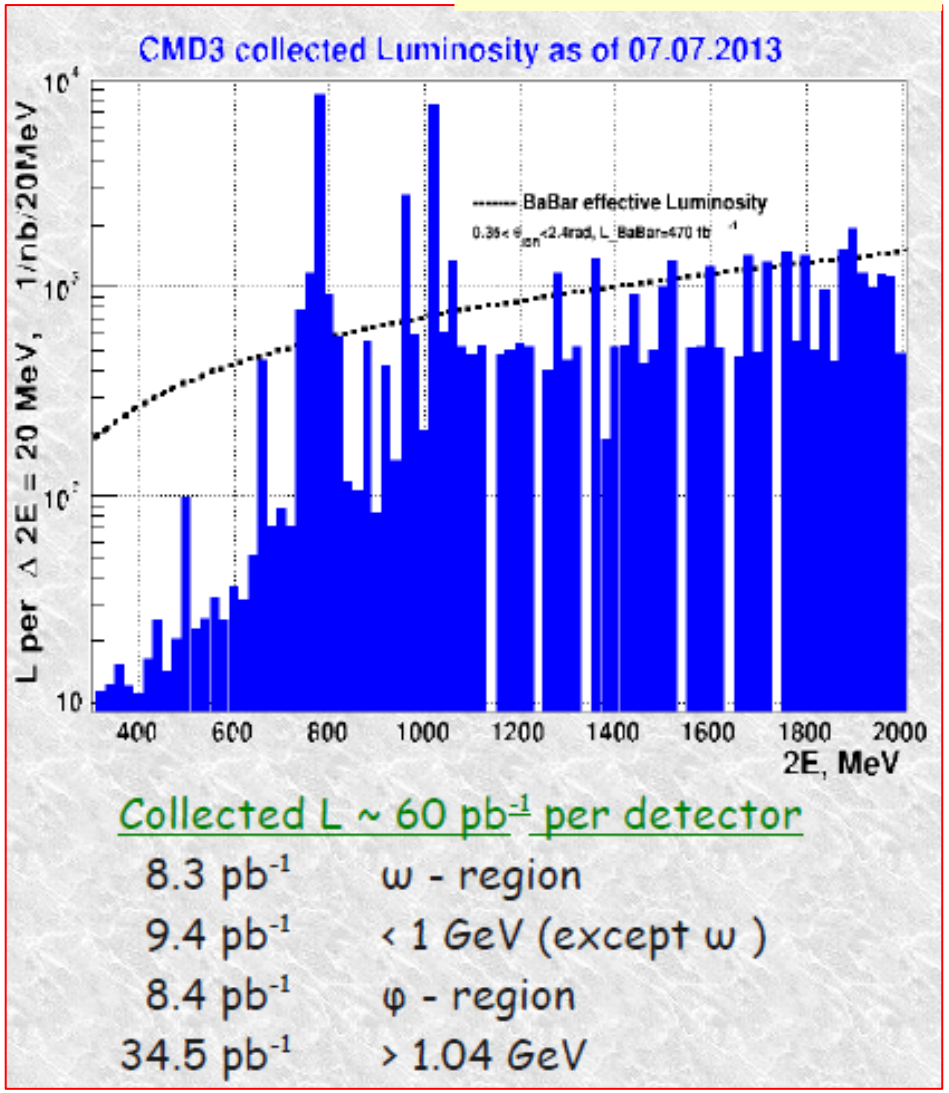
Instant luminosity



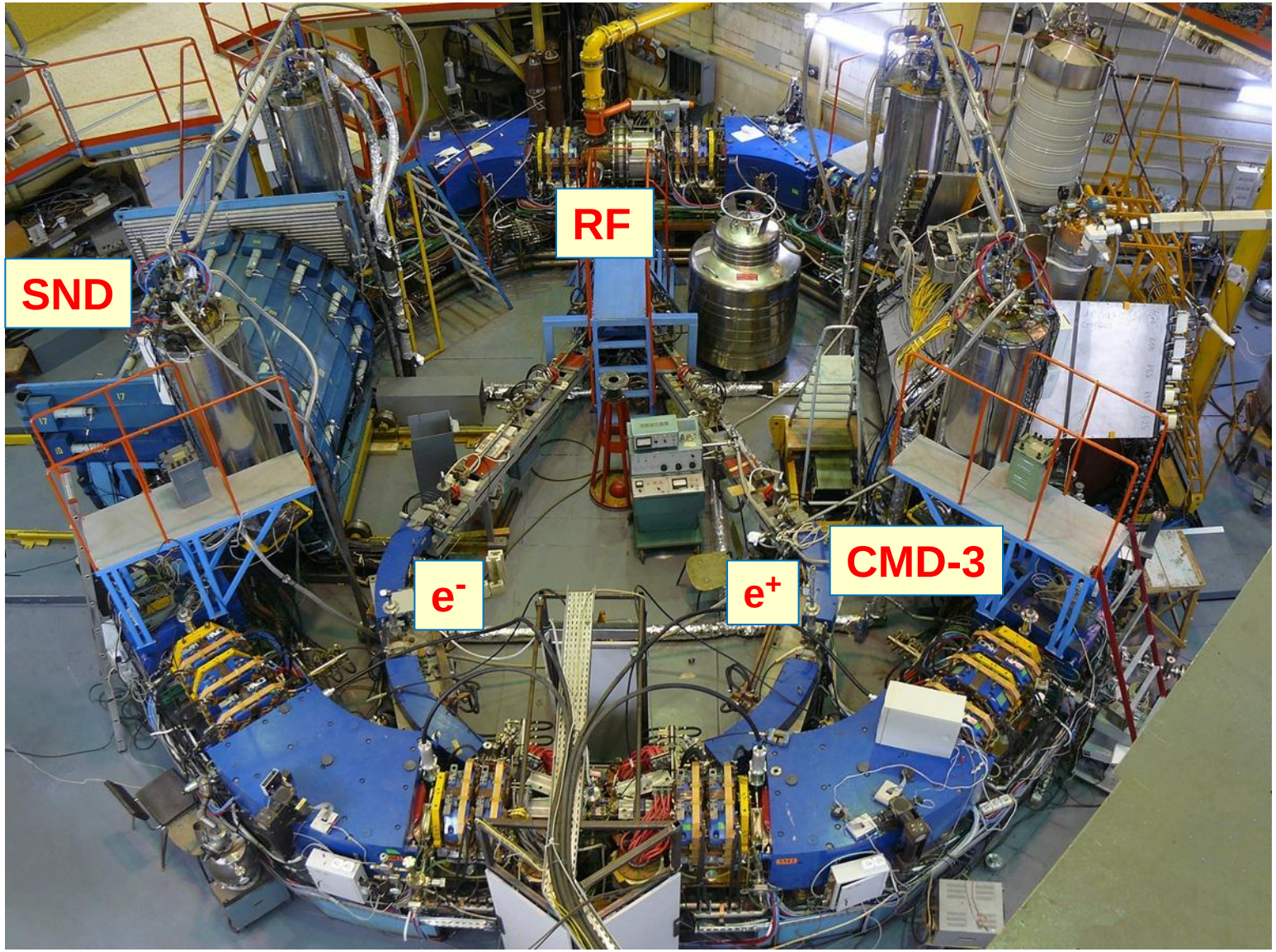
2 × 160 MeV --- the smallest energy ever measured at e^+e^- colliders

The goal - >1 inv.femtobarn !

Integrated luminosity



VEPP-2000 view

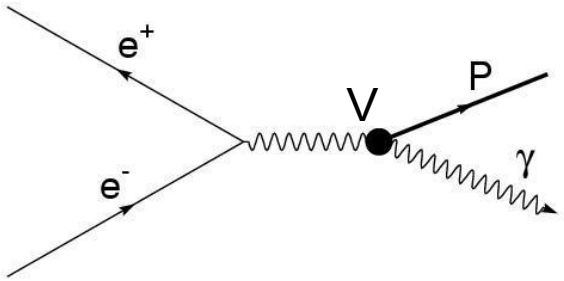


VEPP-2000 physical results, (journal articles)

1. e+e- → $\pi^0\pi^0\gamma$, Phys.Rev.D, (2013)
2. e+e- → 6π, Phys.Lett.B,(2013)
3. e+e- → nn, Phys.Rev.D,(2014)
4. e+e- → NN↔ 6π, JETP Lett.,(2014)
5. e+e- → $\eta\gamma$, Phys.Rev.D,(2014)
6. e+e- → η', Phys.Lett.B,(2015)
7. e+e- → η,η', Phys.Rev.D,(2015)
8. e+e- → $\eta\pi^+\pi^-$, Phys.Rev.D,(2015)
9. e+e- → $\pi^+\pi^-\pi^0$, JETP,(2015)
10. e+e- → K^+K^-, Yad.Fizika, (2015)
11. e+e- → η, JETP Lett.,(2015)
12. e+e- → K^+K^-, Phys.Rev.D,(2016)
13. e+e- → $\omega\eta\pi^0$, Phys.Rev.D,(2016)
14. e+e- → $\omega\eta$, Phys.Rev.D,(2016)
15. e+e- → $\pi^0\gamma$, Phys.Rev.D,(2016)
16. e+e- → $K^+K^-\pi^+\pi^-$, Phys.Lett.B,(2016)
17. e+e- → pp, Phys.Lett.B,(2016)
18. e+e- → K_SK_L, Phys.Lett.B,(2016)
19. e+e- →$\pi^0\pi^0\gamma$, Phys.Rev.D, (2016)

$\rho,\omega,\phi \rightarrow \pi^0\gamma$ study in $e^+e^- \rightarrow \pi^0\gamma$ process

Rhys.Rev.D,93,092001(2016)



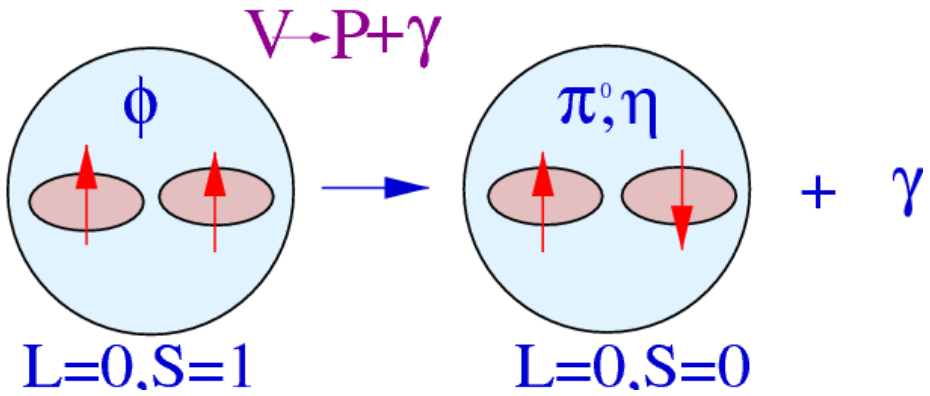
V= ρ,ω,ϕ, P = π^0

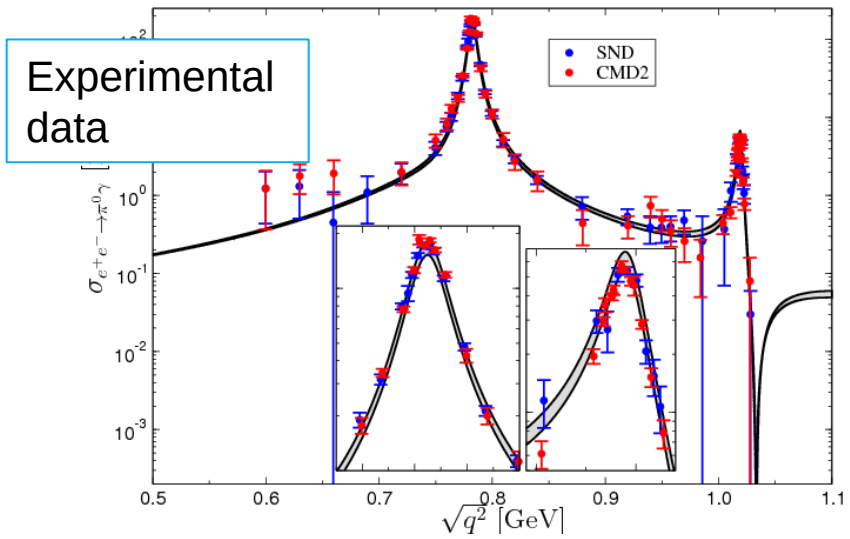
$$\sigma(s) = \frac{q(s)^3}{s^{3/2}}\left|\sum_V A_V(s)\right|^2,$$

$$A_V(s) = \frac{m_V\Gamma_V e^{i\varphi_V}}{m_V^2 - s - i\sqrt{s}\Gamma_V(s)}\sqrt{\frac{m_V^3}{q(m_V^2)^3}\sigma_V},$$

$$q(s) = \frac{\sqrt{s}}{2}\left(1 - \frac{m_{\pi^0}^2}{s}\right),$$

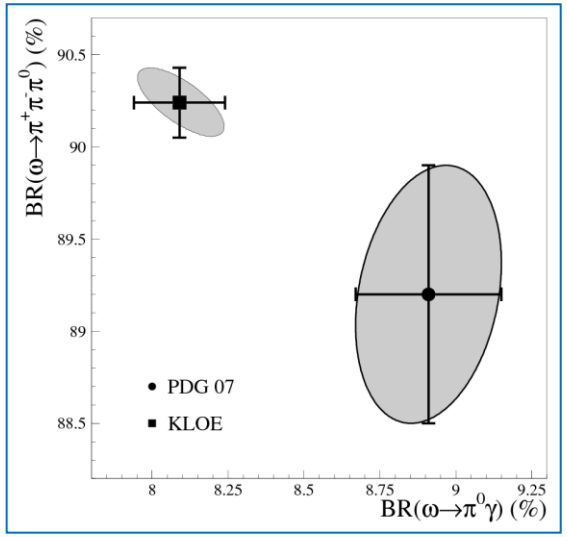
$$\sigma_V = \frac{12\pi}{m_V^2}B(V \rightarrow e^+e^-)B(V \rightarrow \pi^0\gamma).$$



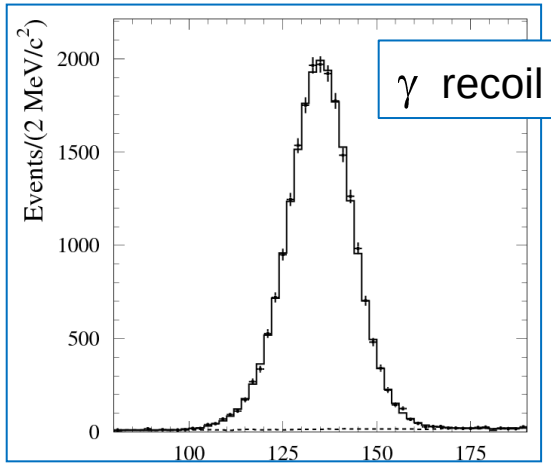


$\omega \rightarrow \pi^0 \gamma$

There is a tension between the KLOE measurement (in $e^+e^- \rightarrow \omega\pi^0$) of the ratio $\Gamma(\omega \rightarrow \pi^0\gamma)/ \Gamma(\omega \rightarrow \pi^+\pi^-\pi^0)$ and other measurements of ω-meson parameters



We measured the $e^+e^- \rightarrow \pi^0\gamma$ cross section at VEPP-2M experiment. Luminosity is 27 inv.pb in the energy range is 0.6-1.38 GeV. The cross section Is fitted with the sum of ρ, ω, ϕ, and V' contributions.

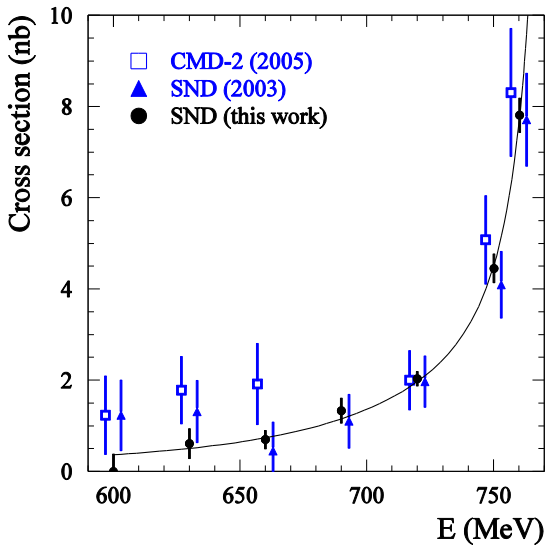


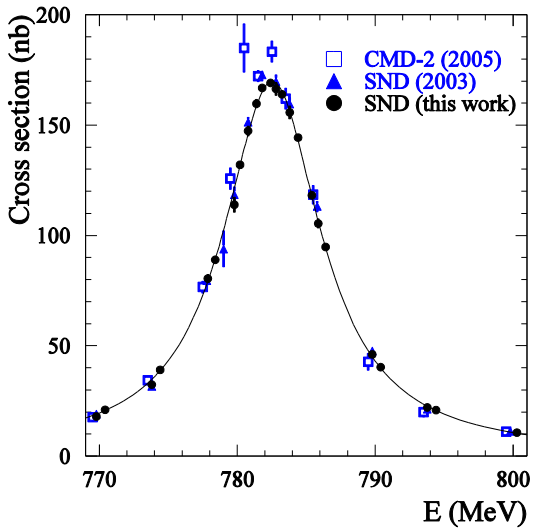
γ recoil spectrum

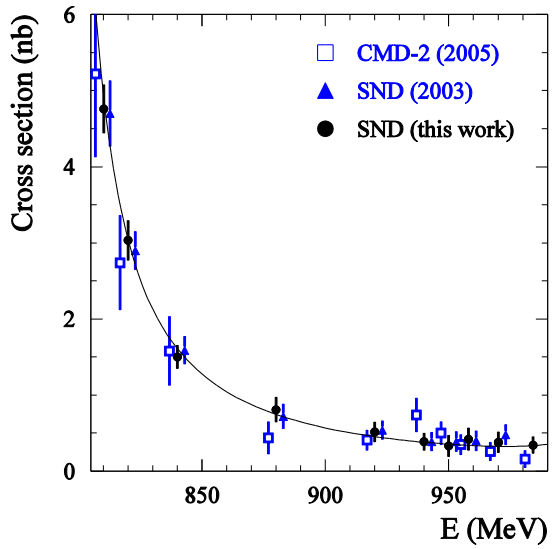
Number of $\pi^0\gamma$ events is obtained from γ recoil spectrum

$\omega \rightarrow \pi^0 \gamma$

Cross section in the ρ, ω region







SND result :

$B(\omega \rightarrow \pi^0\gamma)/B(\omega \rightarrow \pi^+\pi^-\pi^0) = 0.0992 \pm 0.0023$

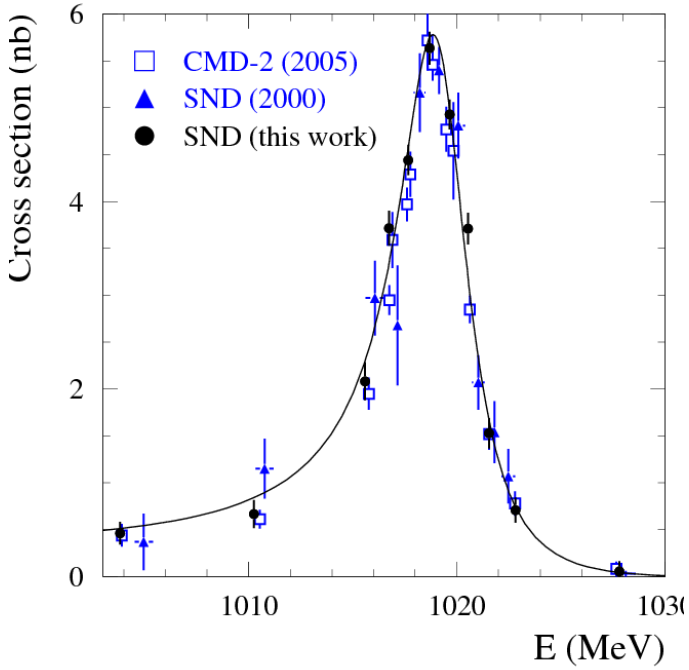
Difference with KLOE (0.0897 0.0016) is 3.4σ

$\rho \rightarrow \pi^0 \gamma$

SND result :

$$B(\rho \to \pi^0\gamma) = (4.20 \pm 0.47 \pm 0.22) \times 10^{-4}$$

By 1.8 σ lower than the current PDG value $(6.0\pm0.8)\times10^{-4}$, but agrees with the branching fraction for the charged mode
$B(\rho^{\pm} \to \pi^{\pm}\gamma) = (4.5\pm0.5)\times10^{-4}$

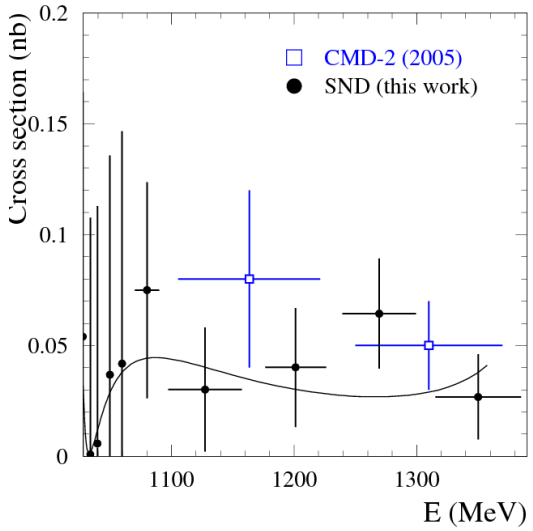


$\phi \rightarrow \pi^0 \gamma$

SND result for φ_ϕ free :

$$B(\phi \to \pi^0\gamma)B(\phi \to e^+e^-) = (3.92^{+0.71}_{-0.40} \pm 0.51) \times 10^{-7}$$

Region above ϕ (1020)



SND result for φ_ϕ fixed :

$$B(\phi \to \pi^0\gamma)B(\phi \to e^+e^-) = (4.04 \pm 0.09 \pm 0.19) \times 10^{-7}$$

$\rho,\omega,\phi \rightarrow \pi^0\gamma$ summary

PDG(2016) This work

$B(\omega \rightarrow \pi^0\gamma) = (8.28 \pm 0.28)\% \rightarrow (8.88 \pm 0.12)\%$

$B(\rho \rightarrow \pi^0\gamma) = (6.0 \pm 0.8)\ 10^{-4} \rightarrow (4.20 \pm 0.52)\ 10^{-4}$

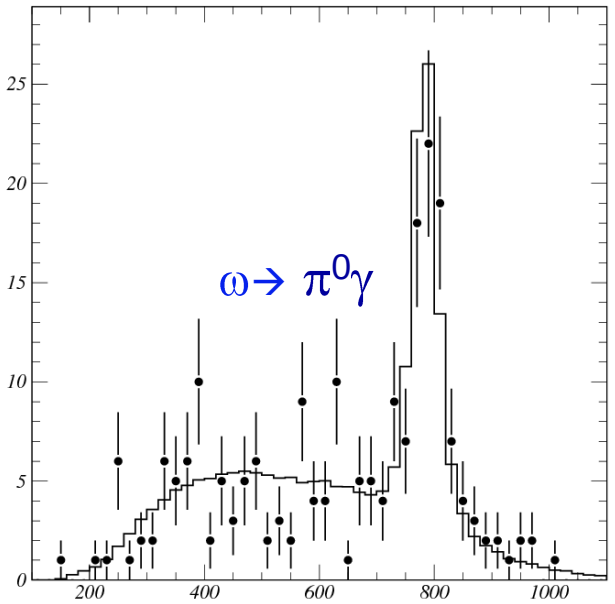
$B(\phi \rightarrow \pi^0\gamma) = (1.27 \pm 0.06)\ 10^{-3} \rightarrow (1.367 \pm 0.072)\ 10^{-3}$

$a_0(980) \rightarrow \eta\pi^0$ in $e^+e^- \rightarrow \omega\pi^0\eta$

Rhys.Rev.D,94,032010(2016)

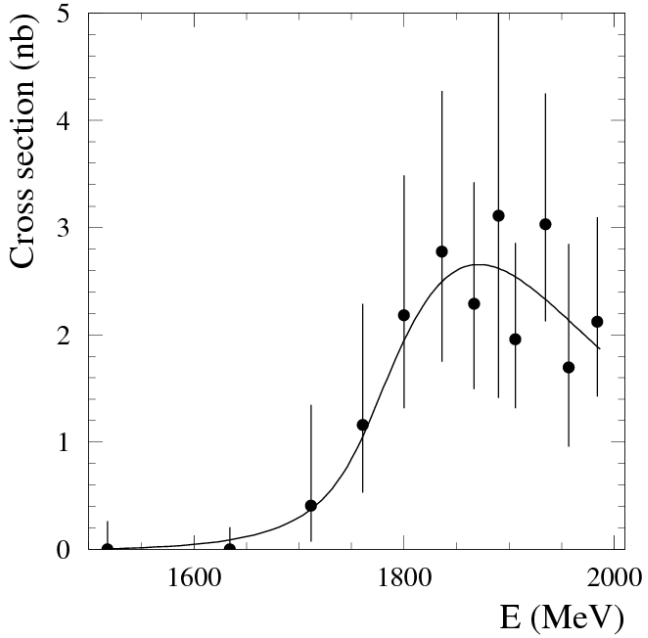
7 photon final state

$e^+e^- \rightarrow \pi^0\pi^0\eta\gamma \rightarrow 7\gamma$

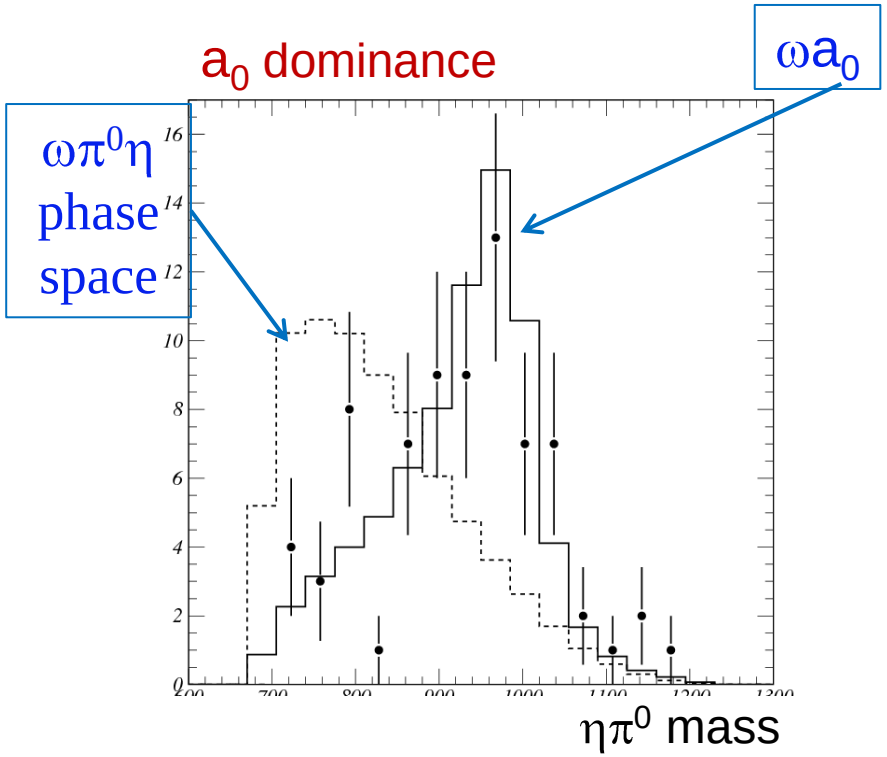


$\pi^0\gamma$ mass

Total cross section



a_0 dominance



$\eta\pi^0$ mass

The cross section is about 2.5 nb,
5% of the total hadronic cross section

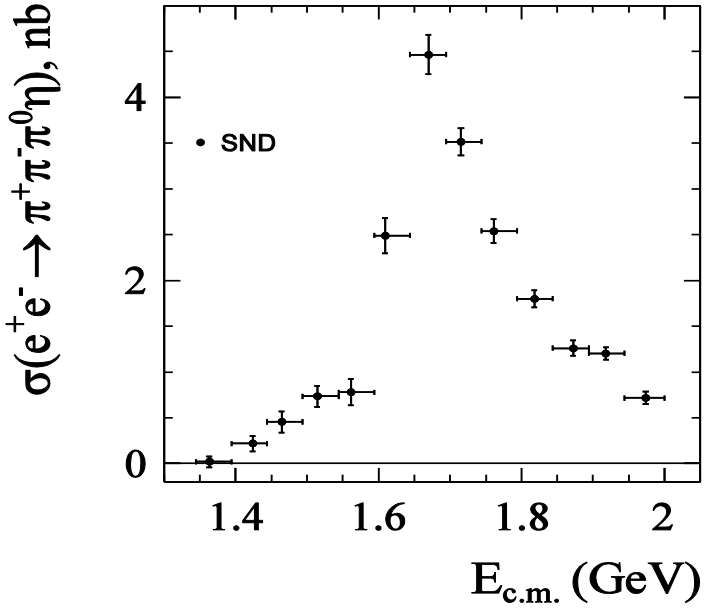
- The $\eta\pi^0$ mass spectrum for selected $\omega\pi^0\eta$ events is well described by the model of the $\omega a_0(980)$ intermediate state

$a_0(980)$ – qq or qqqq state ?

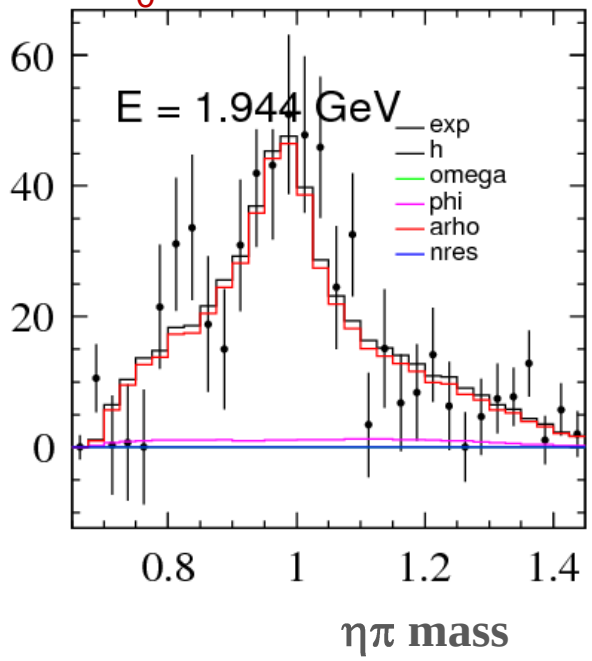
$a_0(980) \to \eta\pi^0$ in $e^+e^- \to \pi^+\pi^-\pi^0\eta$ (1-st measurement)

ρ a_0

Cross section



a_0 dominance

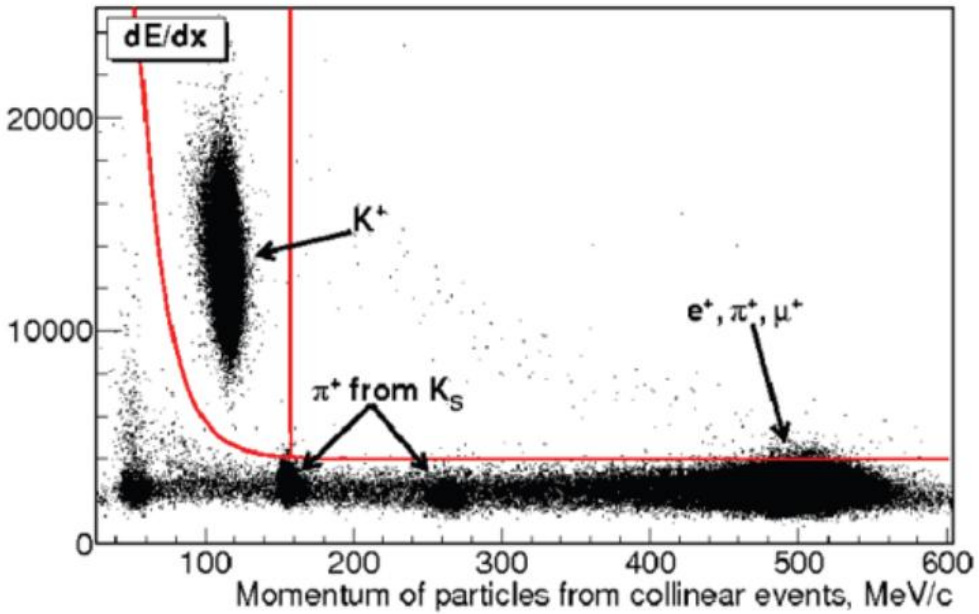


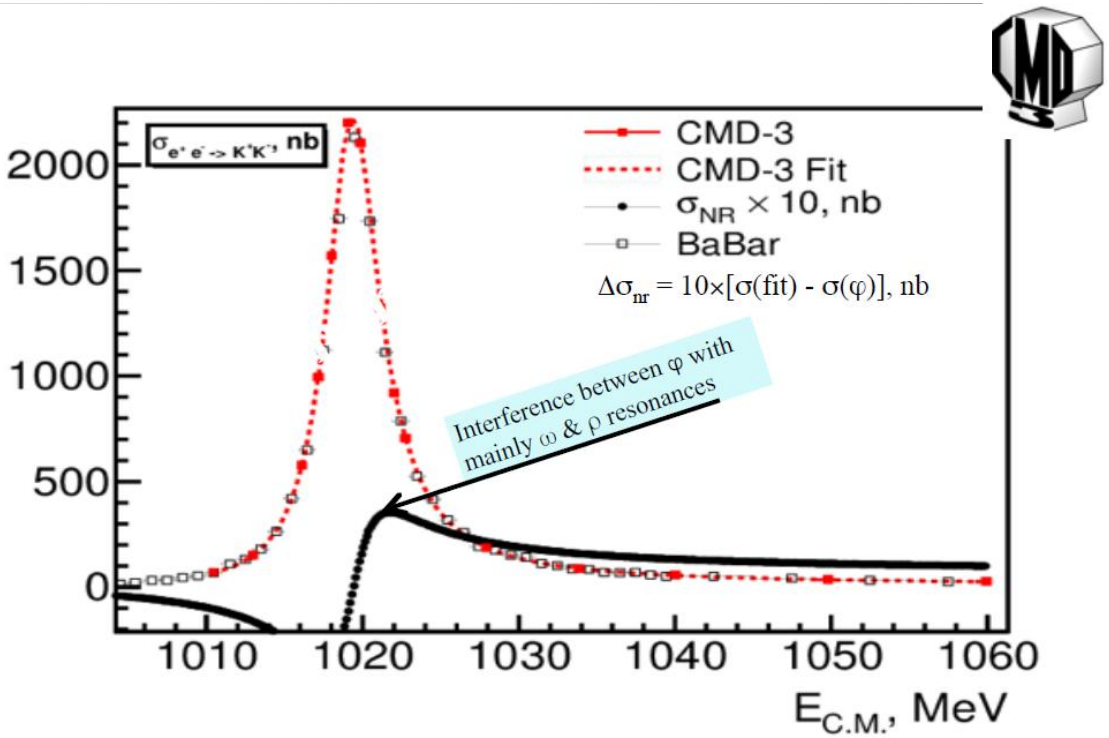
--Above 1.8 GeV the dominant reaction mechanism is $\alpha_0\rho$

-- Other intermediate states below 1.8 GeV are $\omega\eta$, $\phi\eta$, $\alpha_0\rho$ and structureless $\pi^+\pi^-\pi^0\eta$

$e^+e^- \to K^+K^-$ near $\phi(1020)$

Yad.Fizika, 78, 1 (2015)

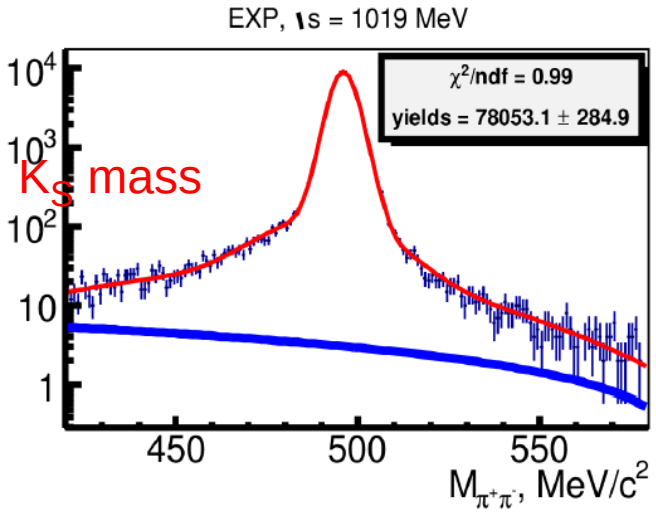


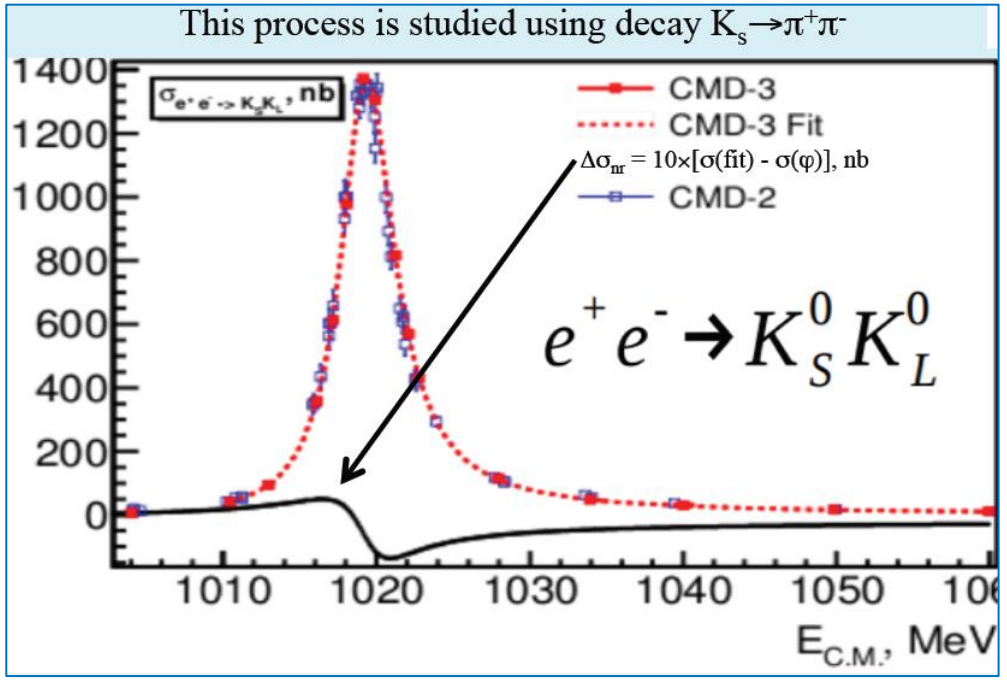


Total luminosity ~ 6 pb^{-1}
Momentum and dE/dX used in selection of K+K- events
Systematic error is 2.5 %
The goal is 1-2% (0.7% BaBar)

$e^+e^- \to K_L K_S$ near $\phi(1020)$

Phys.Lett. B760,314 (2016)





N= 6.10^5 events

$\varepsilon_{det} \sim 0.3$

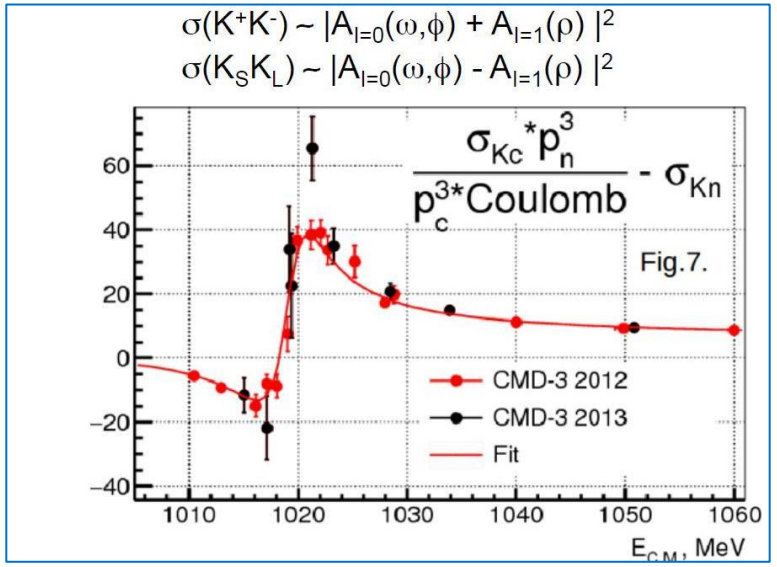
$w_{syst} = 1.8\%$

Fitting

$A \sim \Sigma (A_\phi + A_\omega + A_\rho + A_V)$

Free : M_ϕ, Γ_ϕ, $B(\phi K_S K_L)$

$e^+e^- \to K\bar{K}$ near $\phi(1020)$



Evidence of ρ → KK

Results :

PDG

$m_\phi = 1019.464 \pm 0.060\ \mathrm{MeV}/c^2$ (1019.461+-0.019)

$\Gamma_\phi = 4.247 \pm 0.015\ \mathrm{MeV}$ (4.266+-0.031)

$\Gamma_{\phi\to ee}B_{\phi\to K^0_S K^0_L} = 0.429 \pm 0.009\ \mathrm{keV}$ (0.428+-0.009)

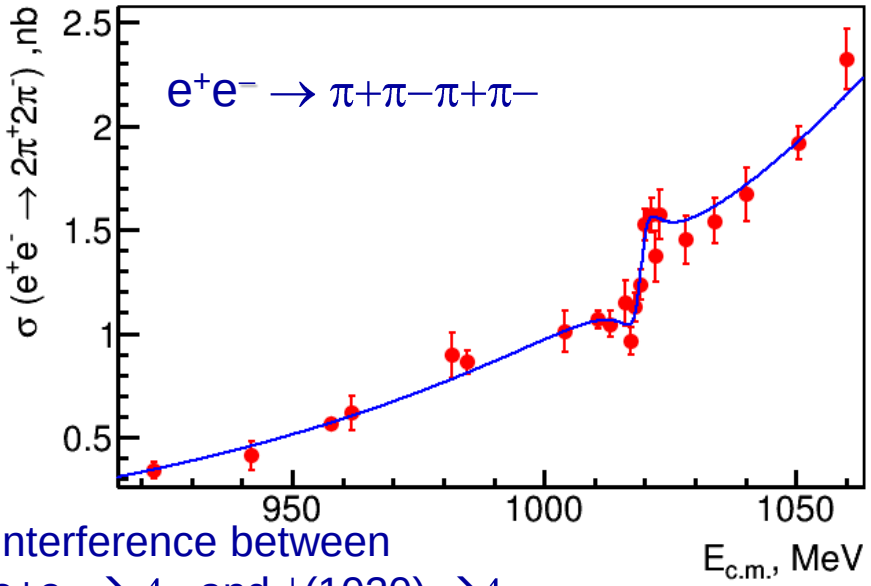
$\Gamma_{\phi\to ee}B_{\phi\to K^+K^-} = 0.679 \pm 0.022\ \mathrm{keV}$ (0.612+-0.012)

$r_{\rho/\omega} = 0.76 \pm 0.11$

$g_{V\to K^+K^-}/g_{V\to K^0_S K^0_L} = 0.995 \pm 0.035$

$e^+e^- \to \pi^+\pi^-\pi^+\pi^-$ near $\phi(1020)$

ArXiv:1612.04483 [hep-ex]



Interference between
e+e- → 4π and φ(1020) →4π
L=10 pb^{-1} , ~8000 events,
$A_1\pi$ - dominance

Two ways for φ(1020) →4π :
-- direct decay, -- via virtual photon

Fitting equation

$$\sigma(E_{c.m.}) = \sigma_0 \cdot f(E_{c.m.}) \cdot \left|1 - Z \cdot \frac{m_\phi \Gamma_\phi}{m_\phi^2 - E_{c.m.}^2 - iE_{c.m.}\Gamma_\phi}\right|^2$$

slope

Z - complex decay amplitude

$$\sigma_0 = 1.263 \pm 0.027 \text{ nb},$$
$$\text{Re } Z = 0.146 \pm 0.030,$$
$$\text{Im } Z = -0.002 \pm 0.024$$

CMD-2

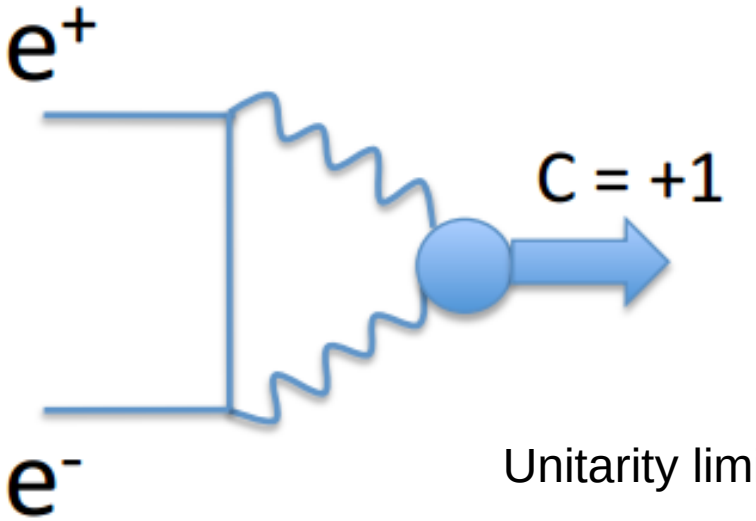
$$(4.0^{+2.8}_{-2.2}) \times 10^{-6}$$

$$\mathcal{B}(\phi \to \pi^+\pi^-\pi^+\pi^-) = \sigma_0 \cdot |Z|^2/\sigma_\phi = (6.5 \pm 2.7 \pm 1.6) \times 10^{-6},$$
$$\sigma_\phi = 12\pi\mathcal{B}(\phi \to e^+e^-)/m_\phi^2 = 4172 \pm 42 \text{ nb}$$

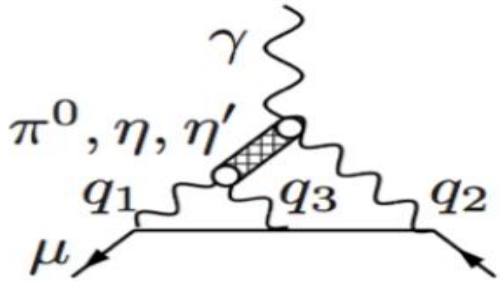
$$\mathcal{B}(\phi \to \gamma^* \to 4\pi) = 9 \cdot \mathcal{B}(\phi \to e^+e^-)^2/\alpha^2 \cdot \sigma_0/\sigma_\phi = 4.8 \times 10^{-6}$$ Im Z=0

Search for C-even resonances in e^+e^-

Direct production of C-even resonances in e+e− collision is possible via a $\gamma\gamma$ intermediate state.



Contribution to $(g-2)_\mu$



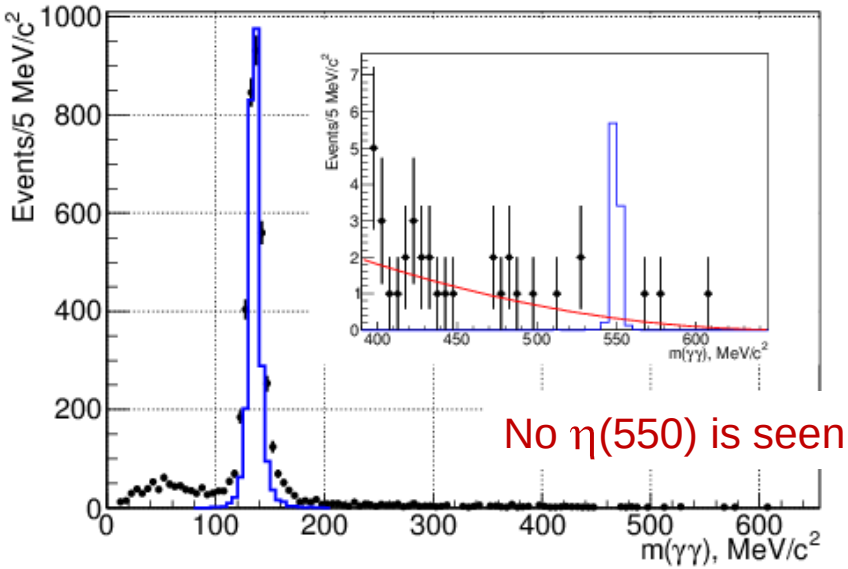
Unitarity limit (via two real γ_s) for $\eta'(958)$: B = 3.75 · 10^{-11},

$$\mathcal{B}_{P\to l^+l^-} = \mathcal{B}_{P\to\gamma\gamma}\frac{\alpha^2}{2\beta}\left(\frac{m_e}{m_P}\right)^2\left[\ln\left(\frac{1+\beta}{1-\beta}\right)\right]^2, \beta = \sqrt{1-4\left(\frac{m_e}{m_P}\right)^2}.$$

$e^+e^- \to \eta'(958)$

CMD3 : Phys. Lett. B740(2015) 273.
SND : Phys. Rev. D 91, 092010 (2015)

Dedicated physics run @ $E_{cm} = M_{\eta'}$
Integrated Luminosity is 2.7 pb^{-1}
Decay $\eta' \to \eta\pi^+\pi^- \to \pi^+\pi^-\gamma\gamma$ was used, CMD3
Decay $\eta' \to \eta\pi^0\pi^0 \to 10\gamma$ was used, SND



Results for $\eta'(958)$:

$\Gamma(\eta' \to e^+e^-)$ < 0.0024 eV (90%CL) - CMD-3
$\Gamma(\eta' \to e^+e^-)$ < 0.0020 eV (90%CL) - SND
$B(\eta' \to e^+e^-)$ < 5.6×10^{-9} (90%CL) - SND+CMD-3

$e^+e^- \to \eta(550)$, feasibility study

Current data:

Existing limit : $B(\eta \to e^+e^-) < 2.3\ 10^{-6}$

Unitarity limit : $B(\eta \to e^+e^-) > 1.8\ 10^{-9}$

SND : JETP. Lett. 102, (2015), 201

2013 VEPP-2000 runs: E_{cm} = 0.5 – 0.6 GeV

Integrated Luminosity is 0.5 pb^{-1}

Instant luminosity is 0.1 inv.μb/sec

Decay $\eta \to \pi^0\pi^0\pi^0 \to \pi^+\pi^-\pi^0, \gamma\gamma$ were studied

Expected limit for η(550) at VEPP-2000 :

$B(\eta \to e^+e^-) < \sim 10^{-6}$ (90%CL) - two weeks of running

Conclusions

1. Since 2010 experiments are carried out at VEPP-2000 e+e- collider in the energy range 0.3 – 2.0 GeV. In 2013 two detectors CMD-3 and SND both accumulated ~ 60 inv.pb of integrated luminosity. Analysis of oldest data from VEPP-2M was continued as well.
2. New more accurate data were obtained by SND on ρ, ω, ϕ radiative decays to $\pi^0\gamma$.
3. Study of $\phi(1020)$ resonance allowed CMD-3 to obtain new data on branching ratios $\phi(1020) \rightarrow K^+K^-$, K_SK_L, $\pi^+\pi^-\pi^+\pi^-$.
4. The dominant contribution of $a^0(980) \rightarrow \pi^0\eta$ was found by SND in $\omega\pi^0\eta$ and $\rho\pi^0\eta$ final hadronic states.
5. New upper limits on electron width of $\eta'(958)$ are obtained in search of $\eta'(958) \rightarrow e^+e^-$ decay.
6. In 2017 the experiments at VEPP-2000 are resumed with new positron source.

Thank you for listening !

Backups

$e^+e^- \to \pi^+\pi^-$ at CMD-3 (I)